DESIGN ANALYSIS AND PERFORMANCE EVALUATION OF CARBON FIBER COMPOSITE RECHARGEABLE IMPACT ABSORBER SPRING

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ABSTRACT

Vehicle safety and impact energy absorption during a crash is one issue of utmost importance in the automobile design. The crash energy absorption in case of an accident is critical and many times prove fatal leading to a majority of deaths in accidents. Present systems for passenger safety like airbags find application in a few of the elite or prime cars to date and also, they have been proved to be insufficient to provide complete safety. One solution to the energy absorption is the application of suitably designed composite springs to absorb maximum kinetic energy during impact and in this course even if there is a failure of the spring it is affordable. Although a carbon fiber composite rechargeable impact absorber spring is a welcome concept where the spring shall absorb the impact energy and the course shall discharge if the system pressure exceeds a preset value and a relief valve is used in this regard. The paper discusses the possibility, design analysis, and experimental performance evaluation of one such composite spring made of carbon fiber. The components have been designed using Unigraphics NX software and the analysis has been done using Ansys Workbench 16.0. The experimental evaluation of the energy absorbed during the crash has been evaluated by the use of a test rig developed for the same purpose.

Keywords: Composite, Rechargeable, Impact, Spring, Crash energy.

I. INTRODUCTION

The problem of an accident of speeding vehicles in road transportation is common but very crucial. Many times, accidents lead to loss of life and property. We cannot avoid accidents completely but the ultimate result of an accident can be reduced by applying safety measures, safety instruments, safety equipment in the form of a reusable sacrificial vehicle crash energy absorber -damper. Present-day safety systems incorporate different devices like airbags and crumple zones.

A structural safety feature in the form of the crumple zone mainly used in automobiles to absorb the impact energy arising during a collision by controlled deformation, During a traffic collision by controlled deformation by crumpling the Crumple zones absorb the energy from the impact which is much greater than is commonly realized energy.

II. PROBLEM STATEMENT

The conventional crumple zones come with the disadvantage that they reduce safety for the passengers of the vehicle as they led the body to collapse, and the crushing puts the occupant at risk. The crumple zones that are typically located in front of the main body of the car in a compact space within the space of the engine compartment to provide far superior protection for their passenger are seen to fail in severe tests against other vehicles with crumple zones and solid stationary objects as compared to the older cars or SUVs that use a separate chassis frame and have no crumple zones. Another difficulty being that these crumple zones tend to come off worse when a vehicle is involved in accidents with SUVs without crumple zones.

III. PROPOSED SOLUTION

The solution to the above problem is offered in the form of a composite spring made of woven carbon fiber, basically bade in two halves namely the BVS top and BVS bottom integrated during the fabrication of the composite spring. The cavity created between the two halves termed as crumple zone cavity and the cavity is filled with hydraulic oil.
This crumple zone cavity will collapse in the process of energy absorption although leading to an increase in the hydraulic oil pressure which when reaches the cracking pressure of the relief valve will be discharged out of the spring and thereby leading to the crumpling of the zone. Although in this process a considerable amount of the crash energy will be absorbed which will ensure the safety of the occupants in case of a crash.

**Figure 1:** BSV Sectional View

**IV. DESIGN AND ANALYSIS**

**BSV Top:**
Material: Epoxy Carbon Woven, 395GP

Hoop stress due to oil pressure:

Maximum pressure induced in the system due to oil = 10 bar = 1 Mpa, using \( f_p = \frac{p \times d}{2t} \) ....(1)

Considering thickness = 1.6 mm

\( f_p = 48.75 \text{N/mm}^2 \)

As \( f_p < f_{\text{all}} \) (allowable stress 300 Mpa) inlet pipe is safe.

**Figure 2:** Oven Carbon Fibre

**Figure 3:** BSV Top
The maximum Von-mises stress is 2.46 Mpa
The maximum deformation is 0.06 mm

Result & discussion:

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Maximum theoretical stress (MPa)</th>
<th>Von-mises stress (MPa)</th>
<th>Maximum deformation mm</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>BVS top</td>
<td>48.75</td>
<td>58.75</td>
<td>0.06</td>
<td>safe</td>
</tr>
</tbody>
</table>

1. Maximum stress by a theoretical method and Von-misses stress is well below the allowable limit, hence the BVS top is safe.
2. BVS top shows negligible deformation under the action of a system of forces.
BSV Bottom:

Material: Epoxy Carbon Woven, 395GPa

Figure 4: BSV Bottom

Hoops stress due to oil pressure:
Maximum pressure induced in the system due to oil = 10 bar = 1 Mpa, using eq. (1)
As $f_{pact} < f_{all}$: (allowable stress 50 Mpa) BVS bottom is safe.

Figure 5: Equivalent Stress for BSV bottom
The maximum Von-mises stress is 42.828MPa
The maximum deformation is 0.001 mm

Table 2. BSV Bottom Result Table

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Maximum theoretical stress (MPa)</th>
<th>Von-mises stress (MPa)</th>
<th>Maximum deformation (mm)</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diverter Pipe</td>
<td>5.575</td>
<td>1.0037</td>
<td>9.032e-6</td>
<td>safe</td>
</tr>
</tbody>
</table>

V. EXPERIMENTAL TESTING

Figure 6: Total Deformation for BSV bottom

Figure 7: Experimental Setup
Testing & Trial of Composite Damper At 10% Excess Pressure Relief.

Objectives of Testing:
Testing of the Composite damper for the following characteristics:
  a) Deformation Vs Impact load
  b) Energy Absorbed Vs Impact load
  c) Percentage Safety Vs impact load

The procedure of the Trial:
1. Load the Composite damper on the test rig.
2. Rotate the handle to move the rack to give spring desired deflection.
3. Release the handle.
4. Note deflection after impact.
5. Repeat.

VI. RESULTS AND DISCUSSION

Table 3. Experimental Result Table

<table>
<thead>
<tr>
<th>Deflection</th>
<th>Potential Energy (J)</th>
<th>Displacement</th>
<th>Energy transferred (J)</th>
<th>Energy Absorbed (J)</th>
<th>% safety</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>2500</td>
<td>0.92</td>
<td>460</td>
<td>2040</td>
<td>81.6</td>
</tr>
<tr>
<td>60</td>
<td>3000</td>
<td>1.1</td>
<td>550</td>
<td>2450</td>
<td>81.66667</td>
</tr>
<tr>
<td>70</td>
<td>3500</td>
<td>1.16</td>
<td>580</td>
<td>2920</td>
<td>83.42857</td>
</tr>
<tr>
<td>80</td>
<td>4000</td>
<td>1.24</td>
<td>620</td>
<td>3380</td>
<td>84.5</td>
</tr>
<tr>
<td>90</td>
<td>4500</td>
<td>1.32</td>
<td>660</td>
<td>3840</td>
<td>85.33333</td>
</tr>
<tr>
<td>100</td>
<td>5000</td>
<td>1.36</td>
<td>680</td>
<td>4320</td>
<td>86.4</td>
</tr>
</tbody>
</table>

Graphs:
1) Graph of Displacement Vs Deflection of Spring

The displacement/deformation of the composite spring increases with an increase in deflection of the spring as the amount of energy absorbed increases.
2) Graph of Energy absorbed Vs Deflection

![Graph of Energy absorbed Vs Deflection](image)

**Figure 9:** Graph of Energy absorbed Vs Deflection

The energy absorbed by the spring increases with the increase in impact force which is the resultant of spring deflection.

3) Graph of Percentage Safety Vs Deflection

![Graph of Percentage Safety Vs Deflection](image)

**Figure 10:** Graph of Percentage Safety Vs Deflection

Maximum safety attained is always above 80% indicating that the device absorbs maximum energy and thereby ensuring the best safety during impact.

**VII. CONCLUSION**

The design of the BVS top shows that the maximum stress induced calculated using the theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.

The design of the BVS bottom shows that the maximum stress induced calculated using the theoretical method as well as the analytical method is well below the allowable stress in the material of the part hence it is safe, so also deformation is negligible.

Testing revealed that the energy absorbed by the spring increases with the increase in impact force which is the resultant of spring deflection.
Testing revealed that maximum safety attained is always above 80% indicating that the device absorbs maximum energy and thereby ensuring the best safety during impact.

VIII. REFERENCES


